RESEARCH REPORT

DETERMINATION OF WATER VAPOUR DIFFUSION ACROSS BRICK MASONRY TREATED WITH WATER REPELLENT SEALERS

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This project was carried out for Canada Mortgage and Housing Corporation. The views expressed are those of the author and do not represent the official views of the Corporation. An earlier project entitled "Performance Evaluation of Water Repellents for Above Grade Masonry" is also available.

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ABSTRACT

The ability for water repellents to allow for water vapour diffusion across treated masonry is an important criteria in the selection of a water repellent. Unfortunately, there appears to be a lack of a standard test procedure to determine the rate of water vapour diffusion across composite materials such as brick masonry assemblies. Standardized methods used in the industry to determine vapour diffusion rates were designed to test uniform sheet materials and are not suitable for composite materials such as brick masonry assemblies.

As part of a CMHC research project, Patenaude Consultants Inc. developed a unique experimental test method for the purpose of evaluating the vapour diffusion characteristics of brick masonry panels treated with various, commercially available, water repellent products. The results indicated that the application of the water repellent products, specifically designed for use on masonry, had no significant impact on the vapour diffusion characteristics of a masonry wall assembly, in comparison to a control sample.

With regards to long term performance, the panel assemblies were moved to an exterior location for weathering at the completion of initial tests. Following exposure to the elements for a period of approximately one year, the panels will be returned to the laboratory for retesting. The findings of these experiments will be the subject of a future report.

Water vapour transmission or "breathability" and resistance to water penetration performance are both important criteria in the selection of a water repellent for a masonry substrate. The issue of water repellency was the focus of an earlier CMHC study summarized by the report entitled "Performance Evaluation of Water Repellents for Above Grade Masonry"; dated May 15, 1997.

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EXECUTIVE SUMMARY

The ability for water repellents to allow for water vapour diffusion across treated masonry is an important criteria in the selection of a water repellent. Unfortunately, there appears to be a lack of a standard test procedure to determine the rate of water vapour diffusion across composite materials such as brick masonry assemblies. Wet cup and dry cup methods are often used in the industry to determine vapour diffusion rates, however, these procedures were designed to test uniform sheet materials and are not suitable for composite materials such as brick masonry assemblies.

Consequently, a unique experimental test method was developed for the purpose of evaluating the water vapour diffusion characteristics of six brick masonry panels of which five were treated with a water repellent product. The sixth panel was left untreated to serve as the control sample. The results have indicated that the application of five commercially available water repellent products, specifically designed for use on masonry, had no significant impact on the vapour diffusion characteristics of a masonry wall assembly, in comparison to the control sample.

The study was conducted at "low" and "high" levels of water vapour pressure difference, obtained by simultaneously exposing the exterior face of each specimen to a very low relative humidity (approximately 7% Rh) while exposing the exterior side to an environment maintained below 30% Rh or 100% Rh. For both test conditions, all environments were maintained between 16 °C and 20°C.

The water vapour transmittance (WVT) of the untreated masonry wall specimen (control sample) was determined to be 0.29 and 0.61 $g/h \cdot m^2$ for the two humidity test conditions, respectively. WVT ratings in the order of 0.21 to 0.25 $g/h \cdot m^2$ and 0.52 to 0.72 $g/h \cdot m^2$ were also obtained for the five tested masonry panels with water repellents applied, as determined at the low and high humidity test conditions. In addition, approximately 70 to 80% and 90 to 100 % "breathability" in comparison to an untreated masonry panel was obtained for the masonry panels treated with a water repellent, for the two water vapour pressure difference test conditions.

With regards to long term performance, the panel assemblies were moved to an exterior location for weathering at the completion of initial tests. Following exposure to the elements for a period of approximately one year, the panels will be returned to the laboratory for retesting. The findings of these experiments will be the subject of a future report.

Water vapour transmission or "breathability" and resistance to water penetration performance are both important criteria in the selection of a water repellent for a masonry substrate. The issue of water repellency was the focus of an earlier CMHC study summarized by the report entitled "Performance Evaluation of Water Repellents for Above Grade Masonry"; dated May 15, 1997.

RÉSUMÉ

La capacité d'un produit hydrofuge de permettre ou non la diffusion de la vapeur d'eau au travers de la maçonnerie constitue un critère important pour le choix d'un tel produit. Malheureusement, il ne semble pas exister de méthode d'essai normalisée pour déterminer le taux de diffusion de la vapeur d'eau au travers de matériaux composites tels que la maçonnerie de brique. On se sert souvent dans l'industrie des procédés de mouillage et de dessiccation pour déterminer les taux de diffusion de la vapeur d'eau; toutefois, ces procédés ont été conçus pour tester les matériaux en feuilles uniformes et ils ne conviennent pas pour les matériaux composites tels que la maçonnerie de brique.

Par conséquent, on a élaboré une méthode d'essai expérimentale unique afin d'évaluer les propriétés de diffusion de la vapeur d'eau de six panneaux de maçonnerie de brique, dont cinq ont été traités au moyen d'un produit hydrofuge. Le sixième panneau n'a pas été traité afin de servir d'échantillon témoin. Les résultats ont permis de constater que l'application de cinq produits hydrofuges différents vendus dans le commerce et conçus spécifiquement pour le traitement de la maçonnerie n'avait aucun effet significatif sur les propriétés de diffusion de la vapeur d'eau d'un mur de maçonnerie, comparativement à l'échantillon témoin.

L'étude a été réalisée à des pressions de vapeur d'eau différentielles « basses » et « élevées », obtenues en exposant la face intérieure de chaque échantillon à un taux d'humidité relative extrêmement bas (environ 7 %) tout en exposant le côté extérieur à un environnement dont le taux d'humidité relative était maintenu au-dessous de 30 % ou à 100 %. Dans les deux conditions d'essai, l'environnement était maintenu à des températures se situant entre 16 et 20 °C.

Le taux de transmission de la vapeur d'eau de l'échantillon de maçonnerie non traité (l'échantillon témoin) s'est établi à 0,29 et 0,61 g/h·m^2 respectivement dans les deux conditions d'essai. On a aussi obtenu des taux de transmission de la vapeur d'eau de l'ordre de 0,21 à 0,25 g/h·m^2 et de 0,52 à 0,72 g/h·m^2 respectivement pour les cinq panneaux de maçonnerie traités au moyen d'un produit hydrofuge, dans les conditions d'essai à taux d'humidité bas et élevé. En outre, on a obtenu des taux de « perméance » approximatifs de 70 à 80 % et de 90 à 100 % pour les cinq panneaux de maçonnerie traités, comparativement au panneau de maçonnerie non traité, dans les deux conditions d'essai de pression de vapeur d'eau différentielle.

Une fois les essais initiaux terminés, on a déplacé les panneaux à l'extérieur afin de les soumettre à l'action des intempéries aux fins d'évaluation de la performance à long terme. Après qu'ils auront été exposés aux éléments pendant une période approximative de un an, les panneaux seront ramenés en laboratoire pour de nouveaux essais. Les résultats de ces expériences feront l'objet d'un rapport ultérieur.

La performance en ce qui a trait à la transmission de la vapeur d'eau ou « perméance » et à la résistance à la pénétration de l'eau sont deux critères importants pour le choix d'un produit hydrofuge destiné au traitement d'un support de maçonnerie. Cette question a déjà fait l'objet d'une étude de la SCHL, résumée dans le rapport intitulé « Évaluation de la performance des produits hydrofuges pour la maçonnerie au-dessus de la surface de la terre » daté du 15 mai 1997.

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1.0 INTRODUCTION

The selection of a water repellent for masonry surfaces is most often based on performance criteria pertaining to water repellency. However, it is equally important to consider the repellent's water vapour diffusion characteristics in the selection process.

The function of the water repellent is two-fold in nature and somewhat contradictory. A water repellent, in order to be considered effective must repel water. In addition, it must also provide the least possible resistance to the diffusion of water vapour. In a northern climate, the presence of a film which behaves as a vapour barrier on the exterior of a wall assembly may result in the premature wear or degradation of the cladding materials. This is as a result of moisture condensing within the outer layers of the cladding material and subsequently freezing if the appropriate exterior conditions exist. In masonry walls, the condition may manifest itself as spalling and/or cracking, if sufficiently exposed to such conditions.

Little information exists on the vapour diffusion characteristics of water repellents applied on composite materials such as masonry wall assemblies. The information which does exist is applicable to uniform materials or substrates.

In order to address these concerns, a test procedure was devised to evaluate the water vapour diffusion characteristics of masonry wall assemblies. The research project presented in this report attempts to evaluate the vapour diffusion characteristics of masonry wall assemblies treated with water repellent sealers.

The aspect of water repellency , covered by a separate study, is presented by the report entitled "Performance Evaluation of Water Repellents for Above Grade Masonry" and should be consulted for resistance to water penetration performance issues. It is the goal of this study to focus on the water vapour diffusion characteristics only.

2.0 OBJECTIVES AND SCOPE OF WORK

The primary objectives of the research work were to develop a practical method to evaluate the vapour diffusion performance of various water repellents applied on masonry wall assemblies, and to determine their effectiveness with regards to vapour diffusion on a comparative basis. As with the previous CMHC study, water repellents were applied to five brick wall specimens with the intent of monitoring short, and long term vapour diffusion performance of the assemblies after exposure. A sixth panel did not receive any water repellent product as it served as a control panel.

The six test specimens were erected within specially designed test frames to permit the installation of a measurement cell to the exterior (low humidity) side of each specimen. The wall specimens were aligned in a hexagon pattern which permitted their simultaneous exposure to various humidity conditions (high humidity side).

Short term performance was the focus of this study. Specimens are currently being weathered to determine the effects of exterior exposure on the applied water repellents with regards to vapour diffusion. This work will be the focus of a separate report.

3.0 PROJECT METHODOLOGY

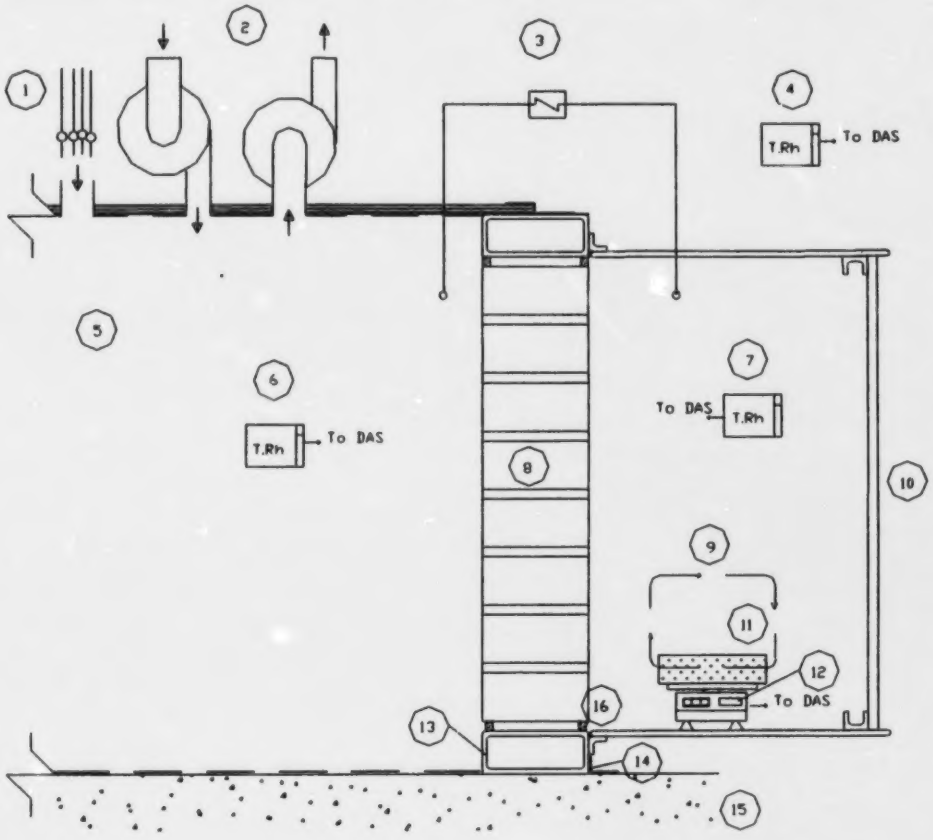
Specially designed test frames were built in which six brick wall specimens were erected and separately treated with five water repellent products for comparative testing. The masonry specimens were constructed under laboratory conditions. Development work and a series of tests were undertaken between October 1996 and December 1998. Refer to appendices A and B for a summary of the tests undertaken during this period. The following is a description of the test apparatus, sample preparation, choice of water repellents and testing methodologies and procedures.

3.1 Test Apparatus

Steel test frames were constructed to receive the six masonry wall panel assemblies. Each test frame measured 718 mm x 641 mm (interior width and height dimensions). The test frames were fitted with hinges to permit the alignment of the six panels in a hexagon pattern at floor level. The treated side of the masonry panels formed the exterior of the hexagon. The apparatus also comprised a movable measurement cell which was used for vapour transmission measurement purposes. Refer to figures no. 1 and 2 for a schematic representation of the test apparatus. The test apparatus design criteria included the following considerations.

- Sample size
- Air pressure equalization
- Humidity generation
- Movable measurement cell
- Simultaneous exposure
- Environment monitoring
- Automated data collection
- Transport for exterior weathering

Although no particular standard exists for the determination of the vapour permeance of masonry panel assemblies, a test procedure comprising a unique test apparatus was devised. As briefly described above, the apparatus essentially was comprised of two major components; a hexagon shaped enclosure for the



1 humid air source
2 mixing blowers (variable speed)
3 differential manometer
4 ambient air temperature & humidity sensor
5 high humidity chamber
6 high humidity chamber temperature & humidity sensor
7 low humidity chamber temperature & humidity sensor
8 brick wall specimen
9 measurement cell (low humidity chamber)
10 glass plate (clear)
11 desiccant tray
12 precision ballance
13 specimen support frame
14 chamber attachment bracket & seal
15 laboratory concrete floor
16 seal

Figure no. 1: Schematic representation of test apparatus

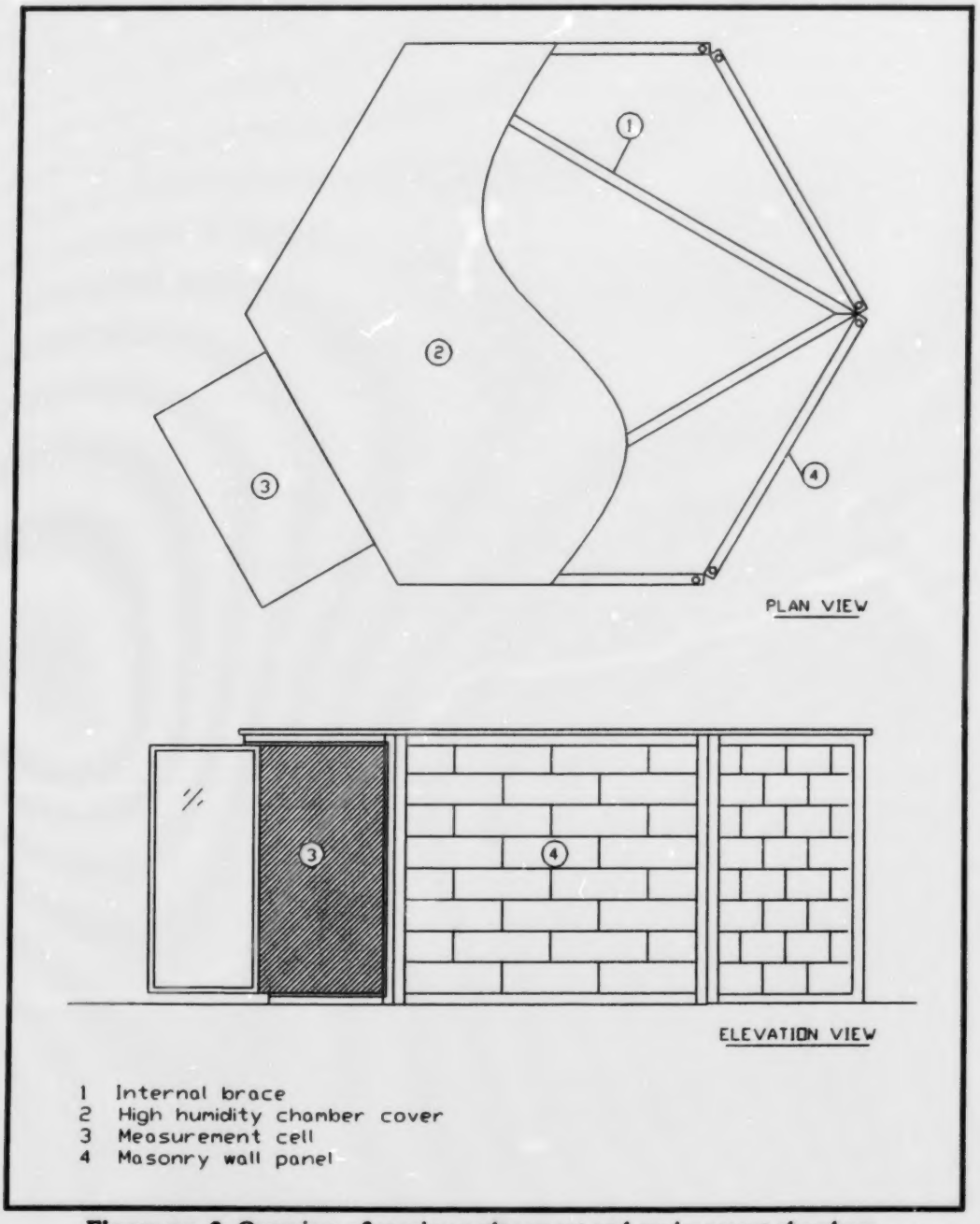


Figure no. 2: Overview of specimen placement and environment chambers.

containment of the high humidity level environment, and a test cell; a rectangular shaped measurement cell for the purpose of measuring the vapour diffusion flow rate through the specimens. In its completed form, the hexagon measured approximately 1830 mm in diameter as measured along its main diagonal, and approximately 770 mm in height. The upper wall of the hexagon was constructed of plywood which was wrapped in a polyvinyl sheet. The entire assembly was laid over a polyvinyl sheet which served as a liner over a concrete floor.

Particular attention was given to the seals between the masonry samples and their surrounding steel support frames, the seal between the measurement cell and samples, and the construction of the measurement cell itself. All joints between masonry and support frames were sealed with a one part polyurethane sealant. To facilitate the attachment and removal of the measurement cell from the individual test specimens, the seal between the measurement cell and the test specimen comprised a closed cell compressible polyethylene foam tape. The walls of the measurement cell were designed to be as impervious to vapour flow as practically possible. As such, its basic plywood construction was lined with an aluminum sheet in which all joints were sealed. In order to permit observation of the interior of the measurement cell, the cell was designed with a glass panel opposite the specimen. The seal between the glass and the walls of the chamber also comprised a compressible, closed-cell polyethylene foam gasket.

A series of support equipment required for the purpose of either generating an humidity environment, or for monitoring or data collection purposes also formed part of the test apparatus. Refer to accompanying photographs and figures. The apparatus was equipped with a vapour generator which provided the necessary humidification for the high humidity environment within the hexagon's enclosed space (ref. photograph no. 1). The low humidity environment within the measurement cell was maintained through a desiccator which comprised a desiccant material (Calcium Sulfate, $CaSO_4$) placed in a multi-tray container with air being forced through it in a circulatory fashion (ref. photograph no. 2). Temperature and humidity conditions were monitored by independent sensor/data collection systems within each of the controlled environments (ref. photograph no. 3).

Differences in static air pressure between the high and low humidity environments were compensated by two variable speed blowers mounted on the top cover of the high humidity chamber. One of these blowers served to extract air from the high humidity environment, while the other was mounted to force

air into it. In this configuration, pressure equalization was obtained and any necessary mixing of humid air with ambient air (for intermediate humidity conditions) was made feasible by simple adjustment of the two blower speeds. Pressure differences were monitored by a digital differential micromanometer, (refer to figure no. 1).

The collection of data was controlled by two separate systems. The monitoring and recording of temperature and humidity conditions was carried out by three independent temperature and relative humidity sensors located in each of the humidity environments (high Rh, low Rh, ambient). Data from these sensors was retrieved at regular intervals by computer interface.

A second system was dedicated to the collection of weight data from a precision electronic balance located within the measurement cell. Changes in weight in the desiccant due to vapour flow were recorded at regular intervals by this system.

3.2 Sample Preparation

Similar to the samples prepared for the resistance to water penetration tests, standard clay bricks measuring 230 mm x 70 mm x 88 mm in addition to pre-mixed mortar were used in preparation of the brick wall specimens. The samples were erected by professional mason and were erected within their steel frames within the same day, under laboratory conditions and in accordance with methods of good building practice.

The completed wall panels comprised 8 rows of brick and measured a total of 752 mm in height by 813 mm in width. The samples were erected within their test frames with a 10 mm joint provided between the masonry and steel framing, for potential thermal and moisture expansion. This perimeter joint was then sealed with a one part polyurethane sealant which served as a vapour seal between the framing and masonry units .

All water repellent products were applied by their respective manufacturer in accordance with their written recommendations and methods of good building practice. Surface preparation by chemical washing was not performed to minimize the potential effects on results (refer to photograph no. 5).

3.3 Choice of Water Repellents

With the goal of maintaining commonality between previous research work, the identical five water repellent products previously selected for the resistance to water penetration tests were also applied for this research project, for comparison purposes. Products were selected from manufacturers based on the following criteria:

- Reputability
- Presence in the market place
- Commitment to product research and development
- Sound technical support
- Product selection
- Willingness to participate

From each of the participating manufacturers product line, a water repellent specially developed for masonry applications was selected. A different product was applied to each of the test panels. One of the test panels was left uncoated as it served as the control panel. In order to protect client confidentiality, the products selected are listed by their generic chemical description as follows:

Panel A:	40% Silane (solvent based)
Panel B:	Polysiloxane blend (solvent based)
Panel C:	Silane/polysiloxane blend (water based)
Panel D:	Siloxane/silane blend
Panel E:	Elastomeric waterproof coating
Panel F:	Control Panel (no coating)

3.4 Testing Methodology

The evaluation of product performance comprised a non-standardized test method. This method was developed to accommodate the size and nature of the specimens. Similar to the dry and wet cup testing methods (ASTM E96), this particular method employed the same basic principle of the cup methods, (i.e., rate of weight change in a quantity of desiccant, at a given vapour pressure difference) as a means of determining the rate of vapour transmission. However, given this similar foundation, several fundamental differences clearly distinguish the method employed from the cup methods.

With regards to test conditions, the environment within the measurement cell (exterior brick face) for the adopted test procedure was maintained at a very low relative humidity of approximately 5 to 7% Rh and the condition of the high humidity environment (inside brick face) was maintained at levels approaching either 30% Rh or 100% Rh (for temperatures between 16 and 20°C). These conditions, differ substantially from the ASTM E96 test procedure, where one side of the sample is exposed to a 50% Rh environment while the other side is subjected to either a very low Rh environment (dry-cup procedure) or a 100% Rh environment (wet-cup procedure).

With regards to testing apparatus, the wet and dry cup methods of ASTM E96, require that a small sample be bonded to a cup containing either desiccant or water and placed in an environment cabinet. The test method utilized made use of a considerably larger sample size and did not make use of a "cup" in the conventional sense. The cup was replaced by a lined box in which a quantity of desiccant was placed over a sensitive electronic balance. This assembly, referred to earlier as a measurement cell, is sealed to the sample's surface.

In the standardized test cup methods, a very good seal is sought at the junction of the cup with the test material and for which leakage is assumed to be insignificant . Given that a relatively quick access to the interior of the measurement cell was required for the purpose of a possible change in desiccant and that the cell itself would require to be transferred often, a gasketing material was selected over a continuous perimeter "wet" seal. This material was selected to be a closed-cell compressible polyethylene foam tape.

Although the selected gasketing material exhibits good vapour resistance properties, the leakage contribution of this type of seal was evaluated at the test conditions by masking the sample area with a piece of plate glass (ref. photograph no.6). The test conducted at the interior dry conditions of the chamber, with electronic balance and desiccant in place, allows for the determination of leakage attributable to the measurement cell. Hence, a net reading was obtained by subtracting the measurement cell leakage rate from the gross measurement reading of a particular test result.

Similar to the ASTM E96 test methods, the determination of the rate of vapour diffusion through a masonry panel assembly required that conditions be maintained so as to obtain a constant rate of weight gain. Once within this steady-state domain, the sample's rate of vapour diffusion may be determined. For the ASTM E96 cup methods, it is the change in the combined weight of the cup, sample, and water (or desiccant) that is used in this determination. In the

adopted test procedure, the weight change in the desiccant material within the measurement cell was used to indicate the rate of vapour diffusion. Water, as a "weighed" material, was not used.

A multi-step process was utilized for the determination of the rate of vapour diffusion through the masonry panel assemblies. A description of the various procedures are summarized as follows.

1) ***Initial Conditioning Period Following Assembly of the Samples***

Following the assembly of the masonry test panels, the specimens were allowed to be conditioned within a relatively dry laboratory environment for a period of 30 days. This period allowed for the final curing of mortar and the drying of the samples prior to testing.

2) ***Assembly of the Test Apparatus***

The sides of the six test panels were hinged and assembled together to form the sides of a closed hexagon. To stabilize its shape, the interior of the hexagon was braced with a triangular support (ref. photograph no. 7). This interior reinforcement permitted the handling and positioning of the assembly without distorting its shape. The hexagon shaped assembly was then positioned over a polyvinyl liner sheet (ref. photograph no. 8) and was capped with a polyvinyl wrapped plywood top. Following the assembly of the hexagonal shape, support equipment including air circulation blowers, a humidity generator and monitoring and measurement equipment, were installed (refer to photograph no.9).

3) ***Product Application***

Water repellent products were applied by their respective manufacturer in accordance with their written recommendations and methods of good building practice. As previously mentioned, surface preparation by chemical washing was not performed, to minimize the potential effects on results (refer to photograph no. 5).

4) ***Preconditioning Period***

Following the assembly of the hexagon, the measurement cell was positioned in front of one of its sides and fixed to the steel frame of the test panel. The humidity generator and blower assemblies were activated and adjusted to

produce the necessary humidity conditions within the enclosed space of the hexagon and balanced so to nullify static air pressure differences across the test specimen. Within the measurement cell, a large desiccator was placed (in place of the balance and smaller capacity desiccator) for a period of time until quasi-steady flow of vapour diffusion across the test sample was achieved, as determined by measurement data. The larger desiccator would ultimately be replaced by a desiccator of smaller scale placed on the measurement pan of the precision balance. In addition, a second larger desiccator would also be installed within a temporary enclosure of a second panel at the outset of the testing and moved ahead of the measurement cell so as to always maintain a preconditioned sample prior to installation of the measurement cell. Each of the samples were preconditioned for a period of at least two weeks prior to installation of the measurement cell.

5) Measurement Period

Following the preconditioning period, a precision electronic balance was installed within the measurement cell with a desiccator mounted over its measuring pan (refer to figure no.1). During a typical test, the gradual increase in weight in the desiccator due to the absorption of moisture by the desiccant material was sensed by the balance. At regular, hourly intervals the weight data would be recorded by a data acquisition system automatically. In addition, in order to monitor the trend in weight gain of the desiccator (for purposes of detecting the steady flow phase) a log of the readings was also displayed by the system. The test was considered terminated when the data indicated a constant rate of weight gain. At this point, the measurement data was collected and the measurement cell was removed and installed for the next panel in the test sequence.

6) Treatment of Data

Once a particular panel test was concluded, the weight data generated from the precision balance and the data stored on the relative humidity and temperature sensors was collected for processing.

Based on the temperature and relative humidity data for the three humidity environments being monitored, the vapour partial pressures for these environments were determined and utilized to calculate the gross vapour flow rate into the measurement cell. As previously discussed, this value was corrected for gains due to leakage across the measurement cell's seals.

7) ***Post Measurement Activities***

Once the testing was completed, the measurement cell was removed from the sample. The saturated desiccant was removed from the desiccators and was prepared for regeneration. The measurement cell was moved to the next panel in the test sequence and prepared for the next measurement cycle, i.e.; loaded with the desiccator and electronic balance.

8) ***Disassembly for Exterior Exposure***

Following completion of the series of tests at high and low vapour pressure difference, the panels comprising the sides of the chamber enclosing the high humidity environment were dismantled. The five samples including the control panel were moved to an exterior location for weathering (ref. photograph no. 10) .The panels were installed with their treated surface facing a southern orientation, respecting the general alignment of six other brick masonry panels utilized as the focus for previous research work pertaining to the study of water repellents and their resistance to water penetration performance.

4.0 DEVELOPMENT OBSERVATIONS

During the course of the project, several observations were noted and are presented as follows.

Following the initial trials of the test apparatus, several changes were incorporated in its design. The initial design of the desiccator/ balance assembly comprised a glass pan loaded with desiccant which was placed upon the balance. The characteristics of the desiccant employed was such that approximately 13% of its original dry weight could be absorbed as moisture. In the initial trials, saturation of the desiccant followed by a rise in humidity within the measurement chamber was noted shortly after the start of the test (approximately a few hours). Given that the desiccant utilized was an indicating type (i.e.,change in colour indicating level of saturation), the apparent saturation of the desiccant was confirmed by a change in colour.

Upon opening of the measurement cell and examination of the desiccant "dish", it was noted that the saturation was limited to the outer layer of the desiccant material; the core of the material remained unaffected. The saturation of the outer layer of desiccant material effectively nullified the vapour absorption process, significantly reducing its drying effectiveness. Subsequently, a different approach at desiccant containment was sought as the simple "dish" method proved ineffective.

After some consideration, a lightweight container was devised to house several layers of desiccant. This desiccator was equipped with two circulating fans to force air through the trays in a circulatory fashion. The increased surface area provided by this method of containment proved successful in extending the effectiveness of the desiccant to meet its manufacturer's performance specifications. However, the apparent successful resolution of the desiccator design was then hindered by unstable balance readings brought on by vibrations and air movement within the measurement cell. These instabilities were resolved by introducing slight modifications to the desiccator casing design and by increasing the dampening of the balance's measurement pan through mechanical (external to balance) and electronic means (internal electronic compensation).

Following completion of the desiccator described above, it was soon realized that the unit, although capable of sustaining low humidity conditions for a considerable length of time, lacked the capacity to endure the relatively lengthy transient regime of vapour diffusion through the test samples. Given the weight limitations imposed by the electronic balance, the smaller lightweight unit was not adequate for the task. A similar but larger device utilizing the same multi-tray principle was then designed to facilitate the attainment of the steady-state vapour flow. As such a two stage approach was devised in which a larger desiccator was used to precondition the samples. Once the steady state regime was achieved, the larger unit was replaced with the smaller measurement cell. In order to expedite the tests, the larger unit was always used ahead in the testing sequence to maintain a preconditioned sample for the measurement cell.

Differences in static air pressure across the samples were also encountered due to the changes in vapour pressure within the measurement cell. This difference was monitored by a capillary tube pressure tap inserted across the seal between the measurement cell and brick sample. A digital manometer connected to the capillary tap displayed the pressure difference across the sample. Differences in the total pressure across the sample were compensated by the adjustment of two blowers installed atop the apparatus in an inversed parallel configuration (ref. figure no. 1). These blowers allowed for the balancing of pressures across the sample through adjustment of their speeds. As a second role, they also served to mix ambient air with humid air (within the hexagon) to create the necessary high humidity environment on the high vapour pressure side of the test sample.

With the resolution of the above difficulties, a series of tests were conducted without any of the masonry coatings applied. This preliminary series of tests had as goal to evaluate the rate of vapour diffusion through the masonry samples prior to the application of the water repellent products. During the course of these trials, it had not yet been determined the extent of time required to attain a steady rate of vapour

diffusion through the samples. A preliminary (and somewhat premature) analysis of the data appeared to reveal a stabilizing trend after approximately one week of exposure to both high and low humidity environments. Based on initial data, coatings were applied to the panels in preparation of a series of comparative tests.

After a curing period of approximately one month , testing resumed with the untreated control sample and data was collected to evaluate the impact of the coating applications on the brick samples (in comparison to untreated panels). Similarly to the previous tests, data was collected at both high and low relative humidity levels.
Following the completion of the first round of tests and a hiatus in the testing of approximately three months, testing of the panel assemblies resumed. As a verification, the control panel and several of the panel assemblies were reverified and revealed a substantially lower rate of vapour flow in comparison to previously obtained results. Following an analysis of the anomaly, it was concluded that the higher rates of vapour diffusion obtained in the preceding series of tests were most probably due to residual moisture present within the panel assemblies. It was also deduced that the first series of tests with the desiccant material may have "dried" the panels of this residual moisture. As such the data collected from this first series of tests was rejected and the experiments were repeated.

Experimentation revealed that exposure periods approaching one month were required to obtain steady vapour flow rates. From this revelation, it was then decided to precondition (i.e., dry out) each of the samples for a two week period. The preconditioning period was then followed by the evaluation period which typically lasted an additional two weeks.

Data collected from experiments conducted after this point appeared to be relatively consistent. Based on these findings, the tests were repeated at both high and low relative humidity levels. However, given that the panels had already been coated with their respective water repellents, the performance data for the uncoated panels could not be reevaluated. Given that the control panel remained as the only uncoated panel and that its uncoated performance compared favourably with the other five panels, it was made the reference for comparing the performance of treated panels.

5.0 SUMMARY OF TEST RESULTS

Based on several months of testing over two years, the following detailed summary of the experimental data and important calculations were compiled for the six masonry panels treated with a water repellent (refer to appendices A and B for more detailed information and calculations). The information presented in these appendices are a detailed summary of the raw data which were collected over the duration of the tests.

As previously mentioned, tests were conducted with panels sandwiched between a high and low relative humidity environment. The low humidity environment was maintained at approximately 7% Rh while the high humidity side was maintained below 100% Rh or 30% Rh (i.e., low/high vapour pressure). Ambient temperatures were maintained between 16 °C and 20°C. For simplicity, a summary of the data presented in Tables A.1 and A.2 of appendices A and B, respectfully, is presented in Table no.1 below.

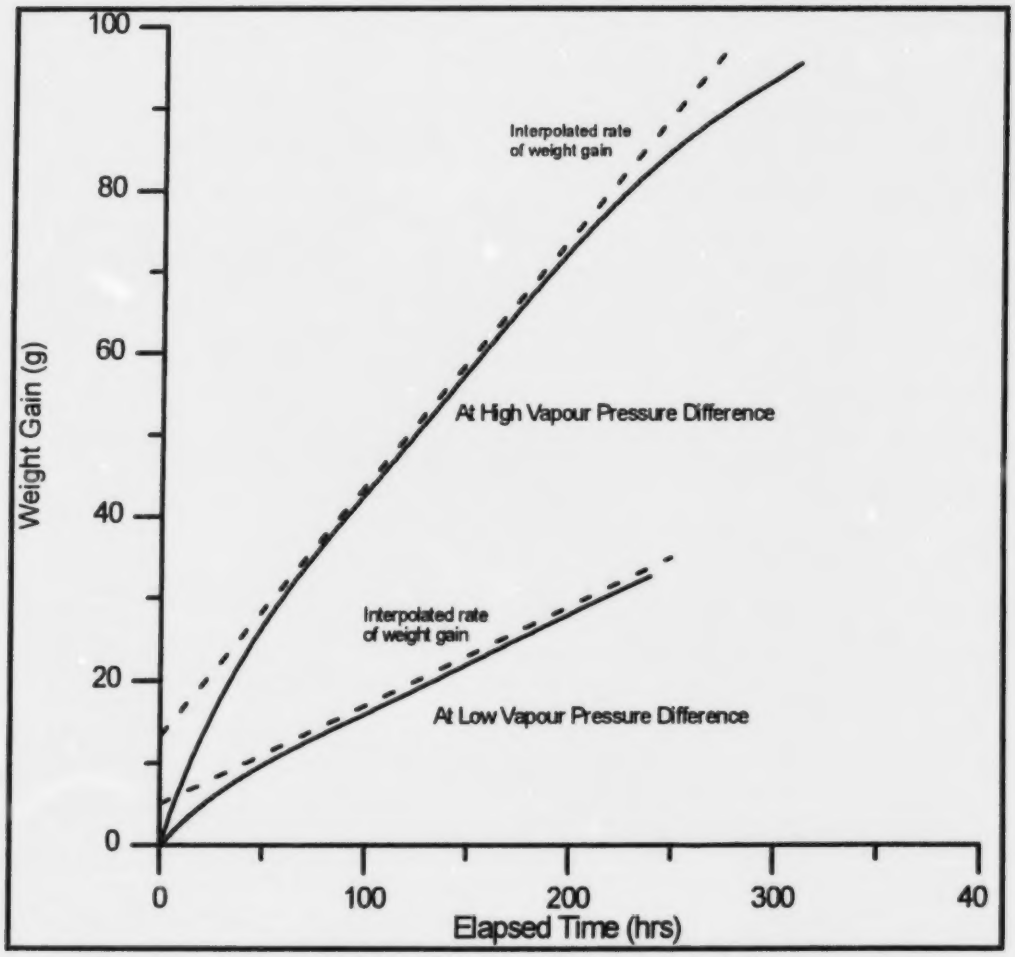


Figure no. 3: Typical relationship of weight increase in desiccant vs. time.

Table no.1: Summary of Water Vapour Tranmittance[1] (WVT) and Breathability[2] of Masonry Panel Assemblies with Applied Water Repellents ($g/h \cdot m^2$)		
Panel	**@ Low Vapour Pressure Difference**	**@ High Vapour Pressure Difference**
A	0.25 (83 %)[3]	0.72 (117 %)
B	0.21 (72 %)	0.68 (110 %)
C	0.25 (87 %)	0.63 (95 %)
D	0.23 (80 %)	0.60 (97 %)
E	0.21 (72 %)	0.52 (84 %)
F[4]	0.29 (-)	0.61 (-)

Notes:

(1) WVT values have been normalized to into account variances in test conditions.

(2) Breathability was determined in comparison to control sample.

(3) The values in parenthesis indicate the percentage transmission of water vapour in comparison to the control panel which did not receive a water repellent.

(4) Control panel, no water repellent product applied.

6.0 ANALYSIS OF RESULTS

A detailed summary of the data and calculations is presented in appendices A and B of this report. The goal of the following sections is to discuss the test results and to evaluate the performance of the products, assemblies and test methods. As with previous research work, the limited data and the preliminary nature of the experiments, will restrict the analysis of the results to a general discussion. Given the limited data, it is not the intent of this report to draw definite conclusions. Rather, the goal will be to assess the available data, understand the performance of the products under evaluation and to evaluate the limitations of the test methods.

As discussed earlier in this report, an evaluation of the "vapour leakage" into the measurement cell from the ambient air was undertaken. The procedure, as described in section 3.4 of this report, required that the measurement cell be isolated from the specimens and tested separately. With a piece of plate glass used as a mask, the nominal rate of vapour leakage into the measurement cell was determined to be 0.035 g/h @ ΔP_v = 1178 Pa (H_2O) from the ambient air. This determination was conducted with the ambient air being approximately at 23°C and 55 % Rh.

As summarized in the preceding tables, rates of vapour diffusion were evaluated at two levels of vapour pressure difference. Given that these partial pressure differences were coarsely controlled, vapour pressure differences ranging from 361 Pa to 518 Pa and 1665 Pa to 2320 Pa were encountered for the series of tests conducted at low vapour pressure difference and high vapour pressure difference, respectively.

Figure no. 3 illustrates the typical plots of the desiccant weight gain data versus elapsed time for the two exposure conditions. The two plots both exhibit a transient phase (curved portion of the curve) followed by a steady phase (straight portion of the curve) where the rate of weight gain is constant with respect to time. A linear curve fit of this area of the curve was then performed to obtain its slope, indicating the rate of weight gain in the desiccant over time, for the steady phase. This value was then corrected to account for leakage of ambient air into the measurement cell. This information in addition to the environmental data (high, low, and ambient conditions) form the basis for the determination of the vapour transmission rate through the panel assemblies.

Table no. 1 also summarizes the WVT results as a percentage value in comparison to the performance obtained for the masonry panel which did not receive a water repellent (control sample). At low vapour pressure difference, WVT results varied from 0.21 to 0.25 $g/h \cdot m^2$ with all panels showing approximately 70 to 80% "breathability" when compared to the reference panel. At high vapour pressure difference, water vapour transmittance ratings for the test panels were calculated to vary between 0.52 and 0.72 $g/h \cdot m^2$ with a corresponding 85% to 117% "breathability" in comparison to the reference panel. In three particular cases (panels A, B, & C), the WVT was determined to marginally exceeded that of the reference panel. For all practical purposes one must attribute this increase to measurement error, carried forth into the calculations. These particular values should be interpreted as being very close to the value obtained for the reference panel.

Given the limited data, the results obtained would appear to indicate that the application of five different water repellents to a brick masonry substrate as part of a panel assembly subjected to a vapour pressure difference, had a marginal impact on the rate of vapour diffusion. Although it would be premature to definitely conclude on the impact a water repellent may have on vapour transmission, more experimentation would be required to draw definite conclusions.

Based on the information available, the following performance ranking was obtained for the panel assemblies/ water repellents tested, as listed in order of decreasing WVT, for the two test conditions.

Table: no. 2: Ranking of Applied Water Repellents as to Breathability[1] (%)	
@ Low Vapour Pressure Difference	*@ High Vapour Pressure Difference*
C: 86 A: 83 D: 79 B: 72 E: 72	A:118 B:111 D: 103 C: 98 E: 85

Notes:
(1): Breathability was determined in comparison to control sample.

Most of the product/panel combinations maintained their general ranking irrespective of the applied vapour pressure difference; these include masonry panels E, D and A. The ranking of panel assemblies B and C changed for the two vapour pressure difference conditions, however given the close grouping of the results, considerably more data would be required prior to making any definite statement regarding the performance evaluation of individual product types or categories.

With regards to performance claims or data which is available from the water repellent manufacturer's literature, most manufacturers claim that their products are "breathable". Table no. 3 presents a comparison of the test results to available performance data published by manufacturers. Note that some manufacturers' data may make reference to an ASTM D1653 test method; specifically oriented to the testing of organic coating films on a non-masonry substrate. Refer to the notes which follow for clarification.

Table no. 3: Summary of Experimental Results and Comparison to Manufacturers' Literature

Panel	@ Low Vapour Pressure Difference		@ High Vapour Pressure Difference		Manufacturers' Literature
	WVT ($g/h \cdot m^2$)	*Breath-ability*[1] (%)	*WVT* ($g/h \cdot m^2$)	*Breath-ability*[1] (%)	*Breathability* (%)
A	0.25	83	0.72	118	100
B	0.21	72	0.68	111	note[2]
C	0.25	86	0.63	98	86
D	0.23	79	0.60	103	note[3]
E	0.21	72	0.52	85	note[4]

Notes:

(1) These values indicate the percentage transmission of water vapour in comparison to the control panel which did not receive any water repellent.

(2) Technical data sheet states that "... the sealer however, is not a vapour barrier."

(3) Technical data sheet makes no mention of "breathability"

(4) Technical data sheet states "... has ability to breathe"

Upon completion of the series of tests at low and high vapour pressure difference, the brick masonry panels were disassembled and moved to the exterior for weathering. The findings following weathering will be the subject of a future report.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of Findings

A unique test method was utilized for the purpose of evaluating the effect on the water vapour diffusion characteristics of six brick masonry panels following the application of water repellent products. The results and analysis of such a study, presented in the previous sections of this report, have indicated that the application of five commercially available water repellent products, specifically designed for use on masonry, had no significant impact on the vapour diffusion characteristics of a masonry wall assembly in comparison to an untreated control specimen.

The study was conducted at two test conditions, in which the exterior face of the specimens were exposed to a dry environment while subjecting their interior face at conditions approaching 30% or 100% Rh. The water vapour transmittance (WVT) values of approximately 0.29 and 0.61 $g/h \cdot m^2$ were determined for an uncoated masonry wall panel at the two test conditions, respectively. WVT's in the order of 0.21 to 0.25 $g/h \cdot m^2$ and 0.52 to 0.72 $g/h \cdot m^2$ were also obtained for the five tested masonry panels with water repellents applied, as determined at the two test conditions. All WVT values were normalized to take into account variances in the test conditions.

In comparison to an untreated masonry panel, water vapour "breathability" in the order of 70 to 80% and 90 to 100 % were obtained for the masonry panels treated with a water repellent, as determined at the two levels of vapour pressure difference.

With regards to long term performance, the panel assemblies were moved to an exterior location for weathering. Following exposure to the elements for a period of approximately one year, the panels will be returned to the laboratory for retesting. The retest following exposure is currently scheduled for the spring of year 2000 and will comprise a repeat of the tests at low and high vapour pressure difference. The findings of this experiments will be the subject of a future report.

7.2 Recommendations

Although the study undertaken proved to be a success, it is clear that continued research of this important topic is required. The limited data obtained from this initiative has brought forth interesting results which demand further investigation. It is recommended that this work be continued and expanded to include a larger sampling so as to produce more definitive results.

Amongst the recommendations which may be put forth in light of the completed work, a review of the test procedure would be in order. Although the procedure is simplistic and effective, it however requires considerable time to obtain results. Vapour diffusion is by nature a very slow process and the means of measurement by desiccant methods are also time consuming. With the goal of improving the test method, effort should be placed in accelerating the procedure wherever possible. This may include the introduction of automation, a review of sample size, procedures, etc. It is also recommended that the measurement method itself be reviewed and consideration be given to researching alternate test methods and technologies which may prove to be more efficient and expedient.

APPENDIX A : SUMMARY OF DATA FOR TRIALS CONDUCTED AT LOW VAPOUR PRESSURE DIFFERENCE

TABLE A.1: DETAILED SUMMARY OF DATA FOR TRIALS CONDUCTED AT LOW VAPOUR PRESSURE DIFFERENCE

Item	Panel A	Panel B	Panel C	Panel D	Panel E	Panel F
Mean Ambient Conditions						
temperature (°C)	16.3	18.0	17.5	17.0	18.0	17.1
relative humidity (%Rh)	18.4	22.6	20.6	18.4	24.7	13.7
P_{sat} (Pa)	1869.9	2082.0	2026.9	1952.4	2082.7	1972.2
P_{vap} (Pa)	344.1	470.6	417.5	359.2	515.4	270.2
Mean High Humidity Conditions						
temperature (°C)	16.0	16.9	16.7	17.0	17.8	16.6
relative humidity (%Rh)	31.8	35.4	32.7	32.9	31.8	27.7
P_{sat} (Pa)	1836.6	1938.9	1920.2	1948.6	2059.0	1909.4
P_{vap} (Pa)	584.0	686.4	627.9	641.1	654.8	528.9
Mean Low Humidity Conditions						
temperature (°C)	16.7	16.9	16.4	17.2	18.4	17.0
relative humidity (%Rh)	8.7	8.6	8.8	8.6	8.1	8.6
P_{sat} (Pa)	1919.5	1939.6	2003.9	1974.9	2144.2	1957.3
P_{vap} (Pa)	167.0	166.8	176.3	169.8	173.7	168.3
Vapour Pressure Differences						
ΔP_{cell} (Pa)	177.1	303.8	241.2	189.4	341.7	101.9
ΔP_{panel} (Pa)	417.0	519.6	451.6	472.3	481.1	360.6
Rates of Vapour Transmission						
Rate of desiccant weight gain-Wg (g/h)	0.111	0.121	0.126	0.120	0.116	0.111
Est. cell leakage-Wc (g/h)	0.005	0.009	0.007	0.006	0.010	0.003
Net vap. trans.- Wn (g/h)	0.106	0.112	0.119	0.114	0.106	0.108
WVT ($g/h \cdot m^2$)	0.23	0.24	0.25	0.24	0.23	0.23
WVT_{norm} ($g/h \cdot m^2$)	0.25	0.21	0.25	0.23	0.21	0.29
% transmission (ref pan. F).	83	72	86	79	72	-

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Project no.: RD-100-C

Data Sheet : Panel A at Low Vapour Pressure Difference

Duration of Experiment: 02-03-1997 to 02-10-1997

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	16.3°C (-2.1°C, + 1.8°C)
Relative Humidity:	18.4 % (-6.4 %, + 6.2 %)
Vapour Pressure @ sat:	1869.9 Pa
Partial Vapour Pressure:	0.184 x 1869.9 Pa = **344.1 Pa**

Measurement Cell Environment

Temperature:	16.7°C (-1.1°C, + 2.1°C)
Relative Humidity:	8.7 % (-0.8 %, + 0.4 %)
Vapour Pressure @ sat:	1919.5 Pa
Partial Vapour Pressure:	0.087 x 1919.5 Pa = **167.0 Pa**

High Humidity Environment

Temperature:	16.0°C (-1.1°C, + 2.1°C)
Relative Humidity:	31.8 % (-9.9 %, + 5.9 %)
Vapour Pressure @ sat:	1836.6 Pa
Partial Vapor Pressure:	0.318 x 1836.6 Pa = **584.0 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	344.1 Pa - 167.0 Pa = 177.1 Pa
$\Delta P_{v\ panel}$:	584.0 Pa - 167.0 Pa = 417.0 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.111 g/h
Estimated cell leakage (Wc):	Wc = 0.035 g/h x 177.1 Pa/1178 Pa = 0.005 g/h
Net rate of vapour flow (Wn):	Wn = Wg - Wc = (0.111 - 0.005) g/hr = 0.106 g/h
Sample area (A):	A = 28 in x 26 in = 0.71 m x 0.66 m = 0.47 m^2
Water Vapour Transmittance (WVT)	= (0.106 g/h) / 0.47 m^2
	= **0.23 g/ h · m^2**

Related Files
Logger: avap24_.stk
Scale: rpana2.dat

Patenaude Consultants inc.

Project no.: RD-100-C

Data Sheet: Panel B Low Vapour Pressure Difference

Duration of Experiment: 02-17-1997 to 03-04-1997

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	18.0°C (-3.4°C, + 2.3°C)
Relative Humidity:	22.6 % (-6.3 %, + 5.7 %)
Vapour Pressure @ sat:	2082.0 Pa
Partial Vapour Pressure:	0.226 x 2082.4 Pa = **470.6 Pa**

Measurement Cell Environment

Temperature:	16.9°C (-2°C, + 1.2°C)
Relative Humidity:	8.6 % (-0.4 %, + 0.7 %)
Vapour Pressure @ sat:	1939.6 Pa
Partial Vapour Pressure:	0.086 x 1939.7 Pa = **166.8 Pa**

High Humidity Environment

Temperature:	16.9°C (-1.9°C, + 1.2°C)
Relative Humidity:	35.4 % (-5.6 %, + 6.9 %)
Vapour Pressure @ sat:	1938.9 Pa
Partial Vapor Pressure:	0.354 x 1938.9 Pa = **686.4 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	470.6 Pa - 166.8 Pa = 303.8 Pa
$\Delta P_{v\ panel}$:	686.4 Pa - 166.8 Pa = 519.6 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.121 g/hr
Estimated cell leakage (Wc):	Wc = 0.035 g/hr x 303.8 Pa/1178 Pa = 0.009 g/hr
Net rate of vapour flow (Wn):	Wn = Wg - Wc = (0.121 - 0.009) g/hr = 0.112 g/hr
Sample area (A):	A = 28 in x 26 in = 0.71 m x 0.66 m = 0.47 m^2
Water Vapour Transmittance (WVT)	= (0.112 g/hr) / 0.47 m^2
	= **0.24 g/ h · m^2**

Related Files
Logger: avap25_.stk
Scale: rpanb2.dat

Data Sheet: Panel C at Low Vapour Pressure Difference

Duration of Experiment: 03-04-1997 to 03-12-1997

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	17.5°C (-1.5°C, + 2.3°C)
Relative Humidity:	20.6 % (-5.0 %, + 3.6 %)
Vapour Pressure @ sat:	2026.9 Pa
Partial Vapour Pressure:	0.206 x 2026.9 Pa = **417.5 Pa**

Measurement Cell Environment

Temperature:	16.4°C (-1.5°C, + 2.0°C)
Relative Humidity:	8.8 % (-0.7 %, + 0.5 %)
Vapour Pressure @ sat:	2003.9 Pa
Partial Vapour Pressure:	0.088 x 2003.9 Pa = **176.3 Pa**

High Humidity Environment

Temperature:	16.7°C (-1.1°C, + 1.4°C)
Relative Humidity:	32.7 % (-4.3 %, + 3.9 %)
Vapour Pressure @ sat:	1920.2 Pa
Partial Vapor Pressure:	0.327 x 1920.2 Pa = **627.9 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	417.5 Pa - 176.3 Pa = 241.2 Pa
$\Delta P_{v\ panel}$:	627.9 Pa - 176.3 Pa = 451.6 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.126 g/h
Estimated cell leakage (Wc):	Wc = 0.035 g/h x 241.2 Pa/1178 Pa = 0.007 g/h
Net rate of vapour flow (Wn):	Wn = Wg - Wc = (0.126 - 0.007) g/hr = 0.119 g/hr
Sample area (A):	A = 28 in x 26 in = 0.71 m x 0.66 m = 0.47 m^2
Water Vapour Transmittance (WVT):	= (0.119 g/h) / 0.47 m^2
	= **0.25 g/ hr · m^2**

Related Files
Logger: avap26_.stk
Scale: rpanc2.dat

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Project no.: RD-100-C

Data Sheet: Panel D Low Vapour Pressure Difference

Duration of Experiment: 03-13-1997 to 03-25-1997

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	17.0°C (-6.0°C, + 2.5°C)
Relative Humidity:	18.4 % (-4.5 %, + 3.4 %)
Vapour Pressure @ sat:	1952.4 Pa
Partial Vapour Pressure:	0.184 x 1952.4 Pa = **359.2 Pa**

Measurement Cell Environment

Temperature:	17.2°C (-1.5°C, + 1.3°C)
Relative Humidity:	8.6 % (-0.5 %, + 0.5 %)
Vapour Pressure @ sat:	1974.9 Pa
Partial Vapour Pressure:	0.086 x 1974.9 Pa = **169.8 Pa**

High Humidity Environment

Temperature:	17.0°C (-1.3°C, + 1.2°C)
Relative Humidity:	32.9 % (-5.1 %, + 9.2 %)
Vapour Pressure @ sat:	1948.6 Pa
Partial Vapor Pressure:	0.329 x 1948.6 Pa = **641.1 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	359.2 Pa - 169.8 Pa = 189.4 Pa
$\Delta P_{v\ panel}$:	641.1 Pa - 169.8 Pa = 471.3 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.120 g/h
Estimated cell leakage (Wc):	Wc = 0.035 g/h x 190.56 Pa/1178 Pa = 0.006 g/h
Net rate of vapour flow (Wn):	Wn = Wg - Wc = (0.120 - 0.006) g/h = 0.114 g/h
Sample area (A):	A = 28 in x 26 in = 0.71 m x 0.66 m = 0.47 m^2
Water Vapour Transmittance (WVT):	= (0.114 g/h) / 0.47 m^2
	= **0.24 g/ h · m^2**

Related Files
Logger: avap27_.stk
Scale: rpand2.dat

Patenaude Consultants inc.

Project no.: RD-100-C

Data Sheet: Panel E at Low Vapour Pressure Difference

Duration of Experiment: 03-25-1997 to 04-04-1997

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	18.0°C (-5.5°C, + 3.6°C)
Relative Humidity:	24.7 % (-4.1 %, + 5.5 %)
Vapour Pressure @ sat:	2082.7 Pa
Partial Vapour Pressure:	0.247 x 2082.7 Pa = **515.4 Pa**

Measurement Cell Environment

Temperature:	18.4°C (-1.4°C, + 1.8°C)
Relative Humidity:	8.1 % (-0.6 %, + 0.5 %)
Vapour Pressure @ sat:	2144.2 Pa
Partial Vapour Pressure:	0.081 x 2144.2 Pa = **173.7 Pa**

High Humidity Environment

Temperature:	17.8°C (-1.4°C, + 1.7°C)
Relative Humidity:	31.8 % (-5.3 %, + 4.1 %)
Vapour Pressure @ sat:	2059.0 Pa
Partial Vapour Pressure:	0.318 x 2059.0 Pa = **654.8 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	515.4 Pa - 173.7 Pa = 341.7 Pa
$\Delta P_{v\ panel}$:	654.8 Pa - 173.7 Pa = 481.1 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.116 g/h
Estimated cell leakage (Wc):	Wc = 0.035 g/h x 341.7 Pa/1178 Pa = 0.010 g/h
Net rate of vapour flow (Wn):	Wn = Wg - Wc = (0.116 - 0.010) g/h = 0.106 g/h
Sample area (A):	A = 28 in x 26 in = 0.71 m x 0.66 m = 0.47 m^2
Water Vapour Transmittance (WVT):	= (0.106 g/h) / 0.47 m^2
	= **0.23 g/ hr · m^2**

Related Files
Logger: avap28_.stk
Scale: rpane2.dat

Project no.: RD-100-C

Data Sheet: Panel F at Low Vapour Pressure Difference

Duration of Experiment: 01-28-1997 to 02-03-1997

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	17.1°C (-1.5°C, + 2.4°C)
Relative Humidity:	13.7 % (-6.0 %, + 6.5 %)
Vapour Pressure @ sat:	1972.2 Pa
Partial Vapour Pressure:	0.137 x 1972.2 Pa = **270.2 Pa**

Measurement Cell Environment

Temperature:	17.0°C (-1.0°C, + 1.1°C)
Relative Humidity:	8.6 % (-0.4 %, + 0.4 %)
Vapour Pressure @ sat:	1957.3 Pa
Partial Vapour Pressure:	0.086 x 1957.3 Pa = **168.3 Pa**

High Humidity Environment

Temperature:	16.6°C (-1.0°C, + 1.1°C)
Relative Humidity:	27.7 % (-5.0 %, + 5.1%)
Vapour Pressure @ sat:	1909.4 Pa
Partial Vapor Pressure:	0.277 x 1909.4 Pa = **528.9 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	270.2 Pa - 168.3 Pa = 101.9 Pa
$\Delta P_{v\ panel}$:	528.9 Pa - 168.3 Pa = 360.6 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.111 g/h
Estimated cell leakage (Wc):	Wc = 0.035 g/hr x 101.9 Pa/1178 Pa = 0.003 g/h
Net rate of vapour flow (Wn):	Wn = Wg - Wc = (0.111 - 0.003) g/hr = 0.108 g/h
Sample area (A):	A = 28 in x 26 in = 0.71 m x 0.66 m = 0.47 m^2
Water Vapour Transmittance (WVT):	= (0.108 g/h) / 0.47 m^2
	= **0.23 g/ hr · m^2**

Related Files
Logger: avap23_.stk
Scale: rpanf2.dat

APPENDIX B: SUMMARY OF DATA FOR TRIALS CONDUCTED AT HIGH VAPOUR PRESSURE DIFFERENCE

TABLE B.1: DETAILED SUMMARY OF DATA FOR TRIALS CONDUCTED AT HIGH VAPOUR PRESSURE DIFFERENCE

Item	Panel A	Panel B	Panel C	Panel D	Panel E	Panel F
Mean Ambient Conditions						
temperature (°C)	19	19.5	17.6	18.0	19.3	15.8
relative humidity (%Rh)	30	32.4	44.3	57.0	48.7	41.9
P_{sat} (Pa)	2218.5	2284.4	2034.1	1955.1	2258.0	1814.0
P_{vap} (Pa)	665.6	740.1	901.1	1114.4	1099.6	760.1
Mean High Humidity Conditions						
temperature (°C)	19.2	20.1	19.0	19.5	21.0	16.9
relative humidity (%Rh)	85.6	94.6	98.9	94.3	96.8	93.8
P_{sat} (Pa)	2244.9	2371.0	2218.5	2284.4	2667.4	1954.9
P_{vap} (Pa)	1921.6	2243.0	2194.1	2154.2	2499.4	1833.7
Mean Low Humidity Conditions						
temperature (°C)	18.9	19.8	18.7	19.2	20.7	17.2
relative humidity (%Rh)	7.9	7.6	8.0	7.8	7.3	8.5
P_{sat} (Pa)	2205.3	2323.9	2178.9	2244.9	2468.3	1983.6
P_{vap} (Pa)	174.2	176.6	174.3	175.6	180.2	168.6
Vapour Pressure Differentials						
ΔP_{cell}	491.4	563.5	726.8	939.3	919.4	591.5
ΔP_{panel}	1747.4	2066.4	2019.8	1979.1	2319.2	1665.1
Rates of Vapour Transmission						
Rate of desiccant weight gain-Wg (g/h)	0.316	0.352	0.329	0.308	0.315	0.261
Est. cell leakage-Wc (g/h)	0.015	0.017	0.022	0.028	0.027	0.018
Net vap. trans. - Wn (g/h)	0.301	0.335	0.307	0.280	0.288	0.243
WVT ($g/h \cdot m^2$)	0.64	0.71	0.65	0.60	0.61	0.52
WVT_{norm} ($g/h \cdot m^2$)	0.72	0.68	0.63	0.60	0.52	0.61
% transmission (ref pan. F)	118	111	103	98	85	-

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Project no.: RD-100-C

Data Sheet: Panel A High Vapour Pressure Difference

Duration of Experiment: 12-07-1998 to 12-22-1998

Mean Environmental Conditions During Steady State Period:

Mean Ambient Environment

Temperature: 19 °C (estimated)
Relative Humidity: 30% (estimated)
Vapour Pressure @ sat: 2218.5 Pa
Partial Vapour Pressure: 0.30x 2218.5 Pa=**665.6 Pa** (estimated)

Measurement Cell Environment

Temperature: 18.9°C (-0.8°C, +0.9°C)
Relative Humidity: 7.9% (-0.4%, +0.3%)
Vapour Pressure @ sat: 2205.3 Pa
Partial Vapour Pressure: 0.079x 2205.3 Pa=**174.2 Pa**

Mean High Humidity Environment

Temperature: 19.2°C (-0.7°C, +1.0°C)
Relative Humidity: 85.6% (-3.3%, 1.9%)
Vapour Pressure @ sat: 2244.9 Pa
Partial Vapour Pressure: 0.856 x 2244.9 Pa=**1921.6 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$: 665.6 Pa - 174.2 Pa = 491.4 Pa
$\Delta P_{v\ panel}$: 1921.6 Pa - 174.2 Pa = 1747.4 Pa

Gross rate of desiccant weight gain (Wg): Wg = 0.316 g/h
Estimated cell leakage (Wc): Wc = 0.035g/h x 490.3Pa/1178Pa =0.015g/h
Net rate of vapour flow (Wn): Wn = Wg -Wc= (0.316 - 0.015)g/h = 0.301g/h
Sample area (A): A = 28 in x 26 in = 0.71m x 0.66m = 0.47 m^2

Water Vapour Transmittance (WVT): =(0.301g/h)/0.47 m^2
= **0.64g/h·m^2**

Related Files

Logger: 2pana_.trw
Scale: 2pana.dat

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Project no.: RD-100-C

Data Sheet: Panel B at High Vapour Pressure Difference

Duration of Experiment: 11-09-1998 to 11-26-1998

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	19.5°C (-2.4°C ,2.5 °C)
Relative Humidity:	32.4 % (-6.3%, +5.2%)
Vapour Pressure @ sat:	2284.4 Pa
Partial Vapour Pressure:	0.324 x 2284.4 Pa=**740.1 Pa**

Measurement Cell Environment

Temperature:	19.8°C (-1.3°C, 2.8°C)
Relative Humidity:	7.6% (-0.5%, 0.5%)
Vapour Pressure @ sat:	2323.9 Pa
Partial Vapour Pressure:	0.076 x 2323.9 Pa=**176.6 Pa**

High Humidity Environment

Temperature:	20.1°C (-1.3°C, +1.5°C)
Relative Humidity:	94.6% (-4.2%, +4.1%)
Vapour Pressure @ sat:	2371.0 Pa
Partial Vapour Pressure:	0.946 x 2371.0 Pa= **2243.0 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	740.1 Pa - 176.6 Pa = 563.5 Pa
$\Delta P_{v\ panel}$:	2243.0 Pa - 176.6Pa = 2066.4 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.352g/h
Estimated cell leakage (Wc):	Wc = 0.035g/h x 563.5 Pa/1178 Pa =0.017 g/h
Net rate of vapour flow (Wn):	Wn = Wg -Wc= (0.352-0.017)g/h = 0.335 g/h
Sample area (A):	A = 28 in x 26 in = 0.71m x 0.66m = 0.47 m^2
Water Vapour Transmittance (WVT):	=(0.3351g/hr)/0.47 m^2 = **0.71g/hr·m^2**

Related Files

Logger: 2pan_.trw
Scale: 2panb.dat

Project no.: RD-100-C

Data Sheet: Panel C at High Vapour Pressure Difference

Duration of Experiment: 10-27-1998 to 11-06-1998

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature: 17.6 °C (-5.9°C, 3°C)
Relative Humidity: 44.3% (-7.7%, +8.4 %)
Vapour Pressure @ sat: 2034.1 Pa
Partial Vapour Pressure: 0.443 x 2034.1 Pa= **901.1Pa**

Mean Chamber Environment

Temperature: 18.7°C (-2.7°C, +1.5°C)
Relative Humidity: 8.0% (-0.5%, +1.0%)
Vapour Pressure @ sat: 2178.9 Pa
Partial Vapour Pressure: 0.08 x 2178.9 Pa=**174.3 Pa**

Mean High Humidity Environment

Temperature: 19°C (-3°C, +1.2°C)
Relative Humidity: 98.9% (-6.7%, +1.1%)
Vapour Pressure @ sat: 2218.5 Pa
Partial Vapour Pressure: 0.989x 2218.5 Pa=**2194.1Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$: 901.1Pa - 174.3Pa = 726.8 Pa
$\Delta P_{v\ panel}$: 2194.1Pa - 174.3 Pa = 2019.8 Pa

Gross rate of desiccant weight gain (Wg): Wg = 0.329 g/h
Estimated cell leakage (Wc): Wc = 0.035 g/hr x 726.8 Pa/1178 Pa =0.022g/h
Net rate of vapour flow (Wn): Wn = Wg -Wc= (0.329- 0.022)g/h =0.307 g/h
Sample area (A): A = 28 in x 26 in = 0.71m x 0.66m = 0.47 m^2

Water Vapour Transmittance (WVT): =(0.307g/h)/0.47 m^2
= **0.65 g/h·m^2**

Related Files

Logger: 2panc_.trw
Scale: 2panc.dat

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Project no.: RD-100-C

Data Sheet: Panel D at High Vapour Pressure Difference

Duration of Experiment: 10-08-1998 to 10-21-1998

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	18.0°C (-3°C, +1.5°C)
Relative Humidity:	57.0% (-11.3%, +24.3%)
Vapour Pressure @ sat:	1955.1 Pa
Partial Vapour Pressure:	0.57 x 1955 Pa=**1114.4 Pa**

Mean Chamber Environment

Temperature:	19.2°C (-1.8°C, 1.4°C)
Relative Humidity:	7.8% (-0.49%, +0.65%)
Vapour Pressure @ sat:	2244.9 Pa
Partial Vapour Pressure:	0.078 x 2244.9 Pa=**175.1 Pa**

Mean High Humidity Environment

Temperature:	19.5°C (-2.1°C, +1.4°C)
Relative Humidity:	94.3% (-23.4%, +5.7%)
Vapour Pressure @ sat:	2284.4 Pa
Partial Vapour Pressure:	0.943x 2284.4 Pa=**2154.2 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$:	1114.4 Pa - 175.1 Pa = 939.3 Pa
$\Delta P_{v\ panel}$:	2154.2 Pa - 175.1 Pa = 1979.1 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.308 g/h
Estimated cell leakage (Wc):	Wc = 0.035g/h x 939.3 Pa/1178 Pa =0.028 g/h
Net rate of vapour flow (Wn)	Wn = Wg -Wc= (0.308 - 0.028)g/h = 0.280 g/h
Sample area (A):	A = 28 in x 26 in = 0.71m x 0.66m = 0.47 m^2
Water Vapour Transmittance (WVT):	=(0.280 g/h)/0.47 m^2 = **0.60g/hr·m^2**

Related Files

Logger:2pand_.trw
Scale: 2pand.dat

Project no.: RD-100-C

Data Sheet: Panel E at High Vapour Pressure Difference

Duration of Experiment: 09-15-1998 to 10-07-1998

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature:	19.3°C (-5.1°C, +5.5 °C)
Relative Humidity:	48.7% (-17.0%, +26.1%)
Vapour Pressure @ sat:	2258.0 Pa
Partial Vapour Pressure:	0.487x 2258.0 Pa= **1099.6 Pa**

Measurement Cell Environment

Temperature:	20.7°C (-4°C, +3.8°C)
Relative Humidity:	7.3% (-1.4%, +1.4%)
Vapour Pressure @ sat:	2468.3 Pa
Partial Vapour Pressure:	0.073x 2468.3 Pa=**180.2 Pa**

High Humidity Environment

Temperature:	21.0°C (3.6°C,3.8 °C)
Relative Humidity:	96.8% (-11.3%, +3.2%)
Vapour Pressure @ sat:	2667.4 Pa
Partial Vapour Pressure:	0.968 x 2582.0 Pa=**2499.4 Pa**

Calculations

Determination of Water Vapour Pressure Differences:

$\Delta P_{v\ cell}$: 1099.6 Pa - 180.2 Pa = 919.4 Pa
$\Delta P_{v\ panel}$: 2499.4 Pa - 180.2Pa = 2319.2 Pa

Gross rate of desiccant weight gain (Wg):	Wg = 0.315 g/h
Estimated cell leakage (Wc):	Wc = 0.035 g/h x 919.4 Pa/1178 Pa =0.027g/h
Net rate of vapour flow (Wn:)	Wn = Wg -Wc= (0.315-0.027)g/h = 0.288 g/h
Sample area (A):	A = 28 in x 26 in = 0.71m x 0.66m = 0.47 m^2
Water Vapour Transmittance (WVT):	=(0.288 g/h)/0.47 m^2
	= **0.61 g/h·m^2**

Related Files

Logger:2pane_.trw
Scale:2pane.dat

Data Sheet: Panel F at High Vapour Pressure Difference

Duration of Experiment: 05-05-1997 to 05-20-1997

Mean Environmental Conditions During Steady State Period:

Ambient Environment

Temperature: 15.8°C (-4.5°C,+3.3 °C)
Relative Humidity: 41.9% (-18.1%, +13.7%)
Vapour Pressure @ sat: 1814.0 Pa
Partial Vapour Pressure: 0.419 x 1814.0 Pa= **760.1 Pa**

Measurement Cell Environment

Temperature: 17.2°C (-2.6°C, +1.9°C)
Relative Humidity: 8.5% (-0.70%, +0.95%)
Vapour Pressure @ sat: 1983.6 Pa
Partial Vapour Pressure: 0.08 x 1983.6 Pa=**168.6 Pa**

Mean High Humidity Environment

Temperature: 16.9°C (-2.7°C, +2.1°C)
Relative Humidity: 93.8% (-----%, 6.1%)
Vapour Pressure @ sat: 1954.9 Pa
Partial Vapour Pressure: 0.938 x 1954.9 Pa=**1833.7 Pa**

Calculations

Determination Water Vapour Pressure Differnces:

$\Delta P_{v\ cell}$: 760.1 Pa - 168.6 Pa = 591.5 Pa
$\Delta P_{v\ panel}$: 1833.7 Pa - 168.6 Pa = 1665.1 Pa

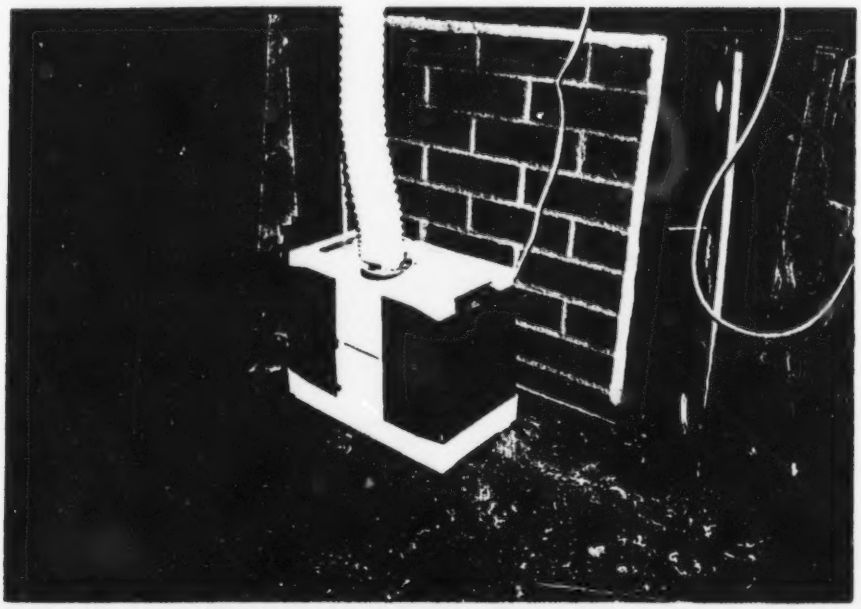
Gross rate of desiccant weight gain (Wg): Wg = 0.261 g/h
Chamber leakage (Wc) Wc = 0.035 g/h x 591.5 Pa/1178 Pa =0.018 g/h
Net rate of vapour flow (Wn) Wn = Wg - Wc= (0.2609 - 0.018)g/h = 0.243g/h
Sample area (A): A = 28 in x 26 in = 0.71m x 0.66m = 0.47 m^2

Water Vapour Transmittance (WVT): =(0.243 g/hr)/0.47 m^2
= **0.52 g/h·m^2**

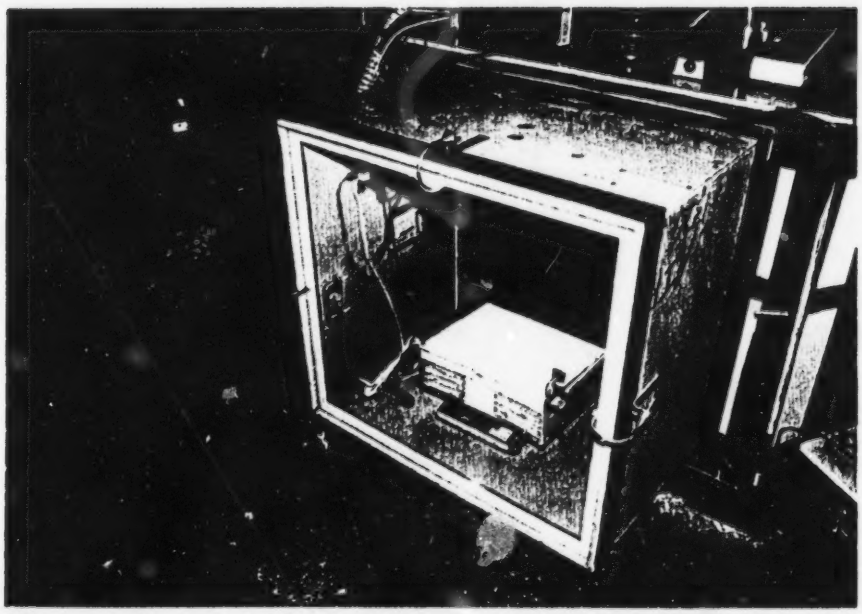
Related Files

Logger: avap40_.stk
Scale: rpanf.3_.dat_

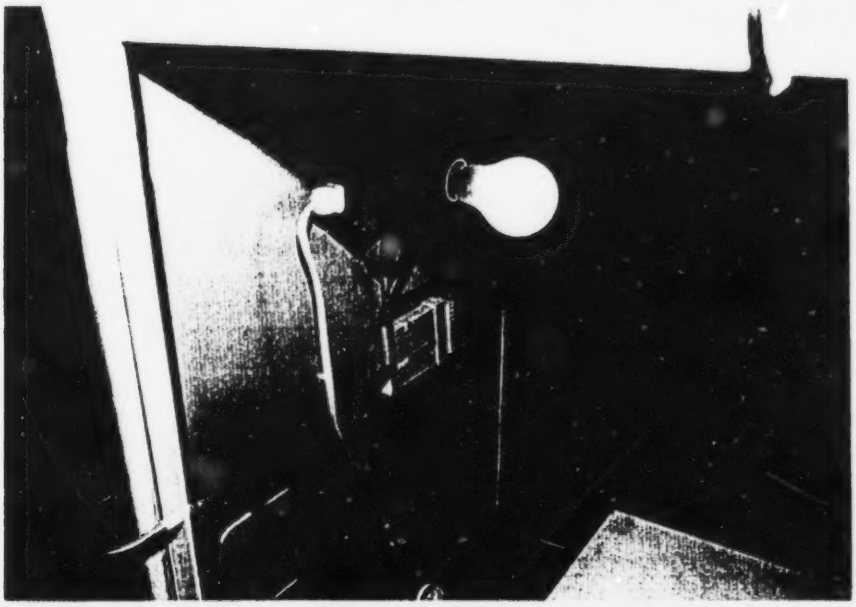
APPENDIX C: PHOTOGRAPHS



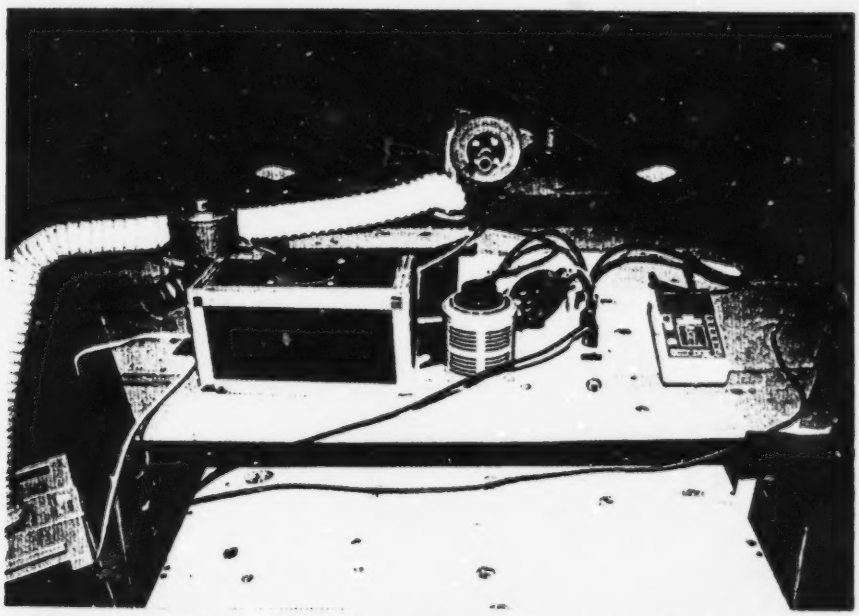
Photograph no. 1: Humidity generator



Photograph no. 2: Measurement cell containing precision balance and desiccator

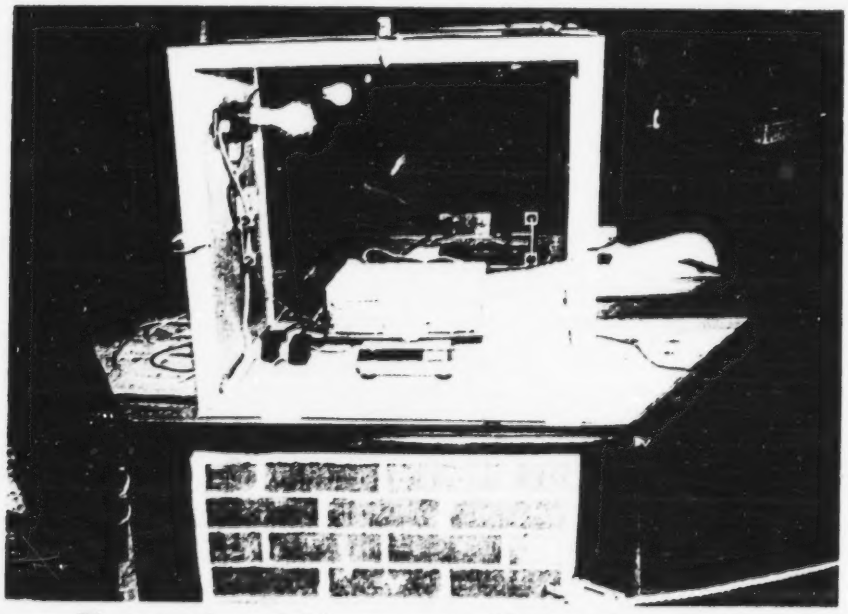


Photograph no. 3: Temperature and humidity recorder within measurement cell.

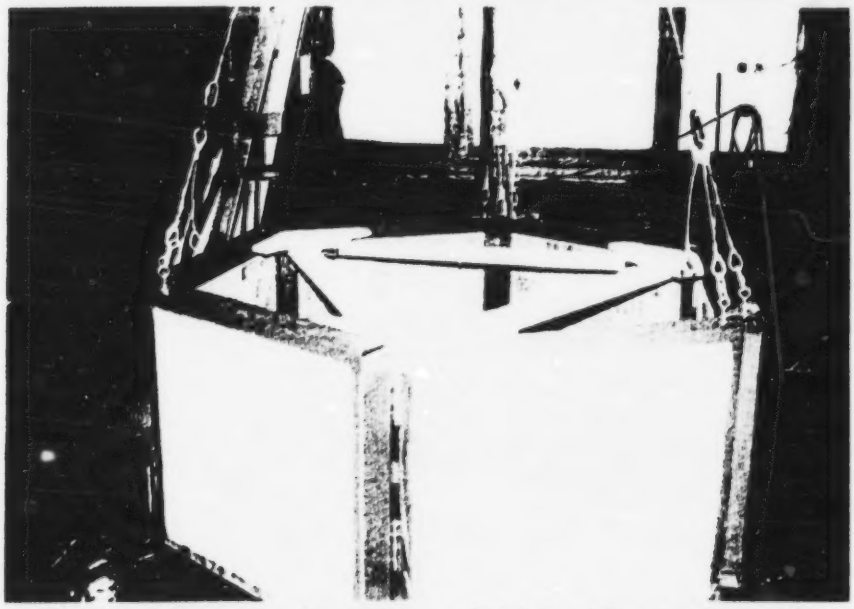


Photograph no. 4: Top view of high humidity chamber (including, blowers, controls and manometer)

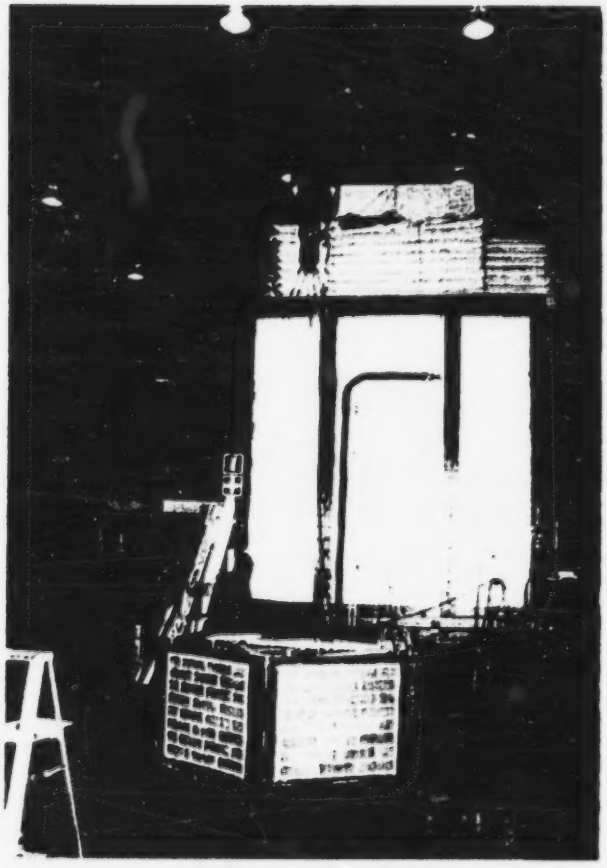
Photograph no. 5: Application of water repellents on masonry surfaces



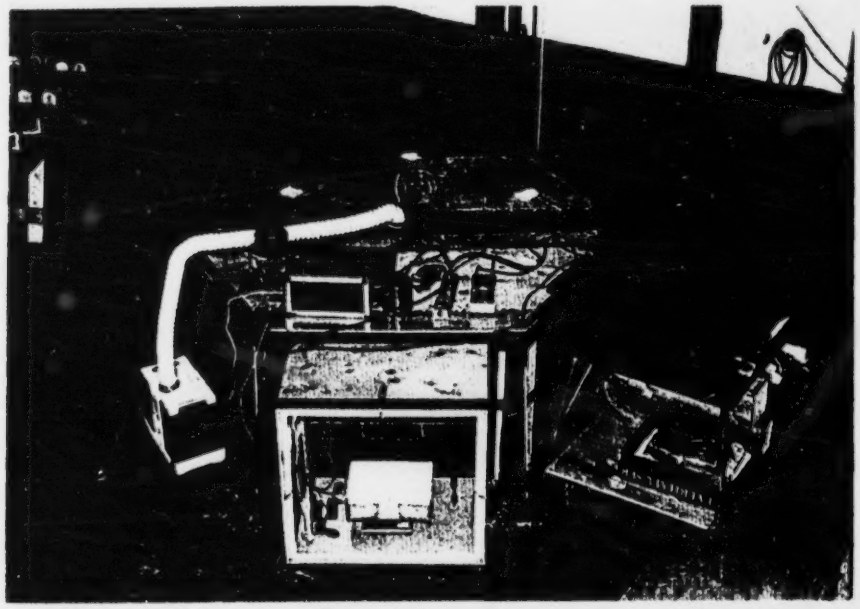
Photograph no. 6: Measurement cell leakage determination



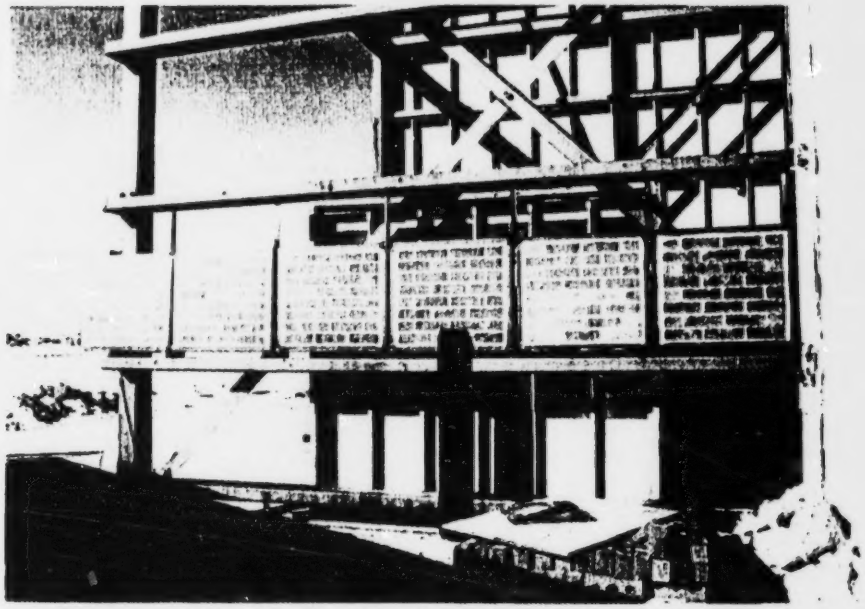
Photograph no. 7: Internal view of high humidity chamber (with bracing) prior to final assembly



Photograph no. 8: Positioning of test apparatus



Photograph no. 9: General view of test apparatus and support equipment.



Photograph no. 10: Transfer of panels to exterior for weathering.